

Figure 5. Full Infiltration Basin Design  
(Source: Schueler 1987)

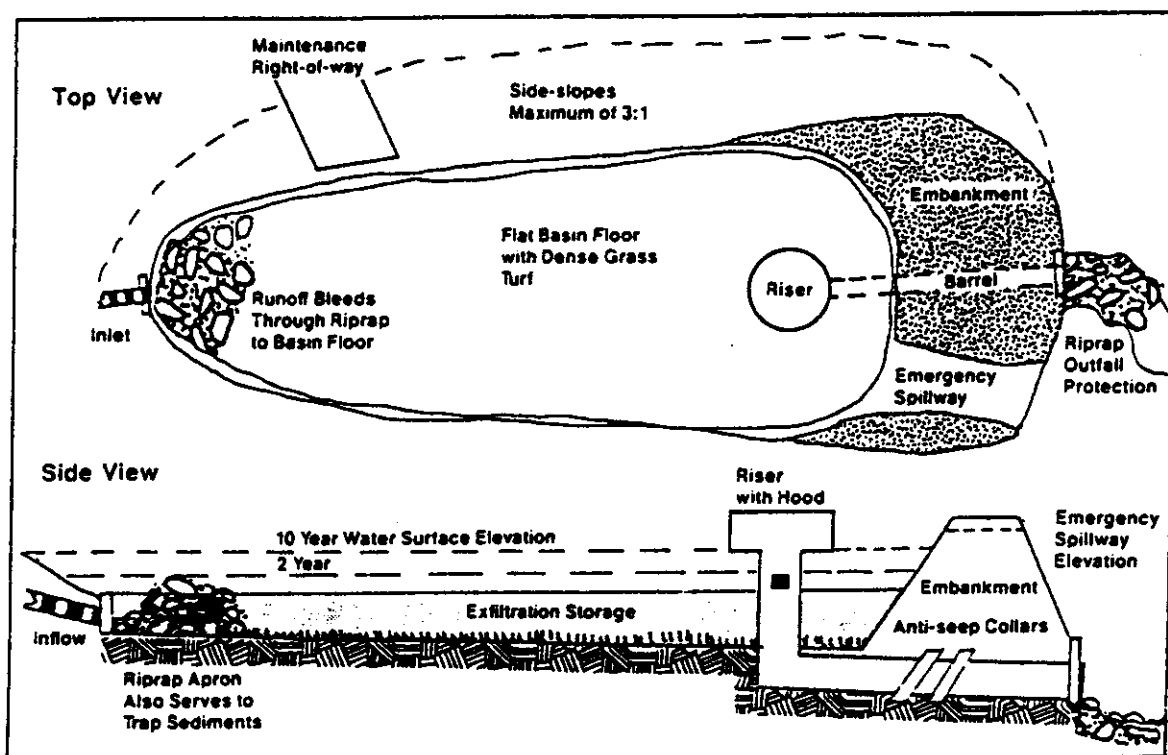


Figure 6. Schematic of Combined Infiltration/Detention Basin Design  
(Source: Schueler 1987)

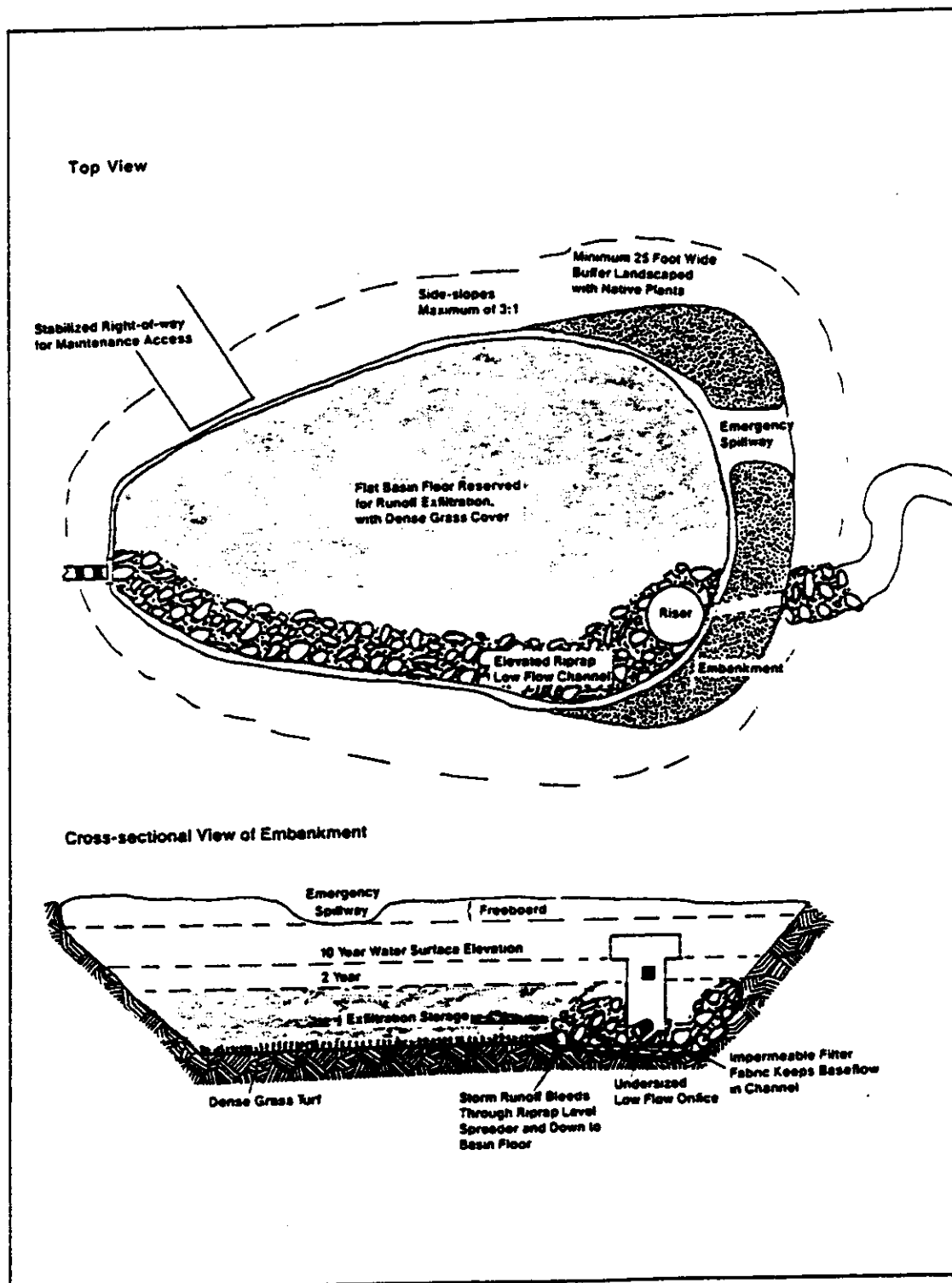


Figure 8. Schematic of Side-by-Side Infiltration Basin Design  
(Source: Schueler)

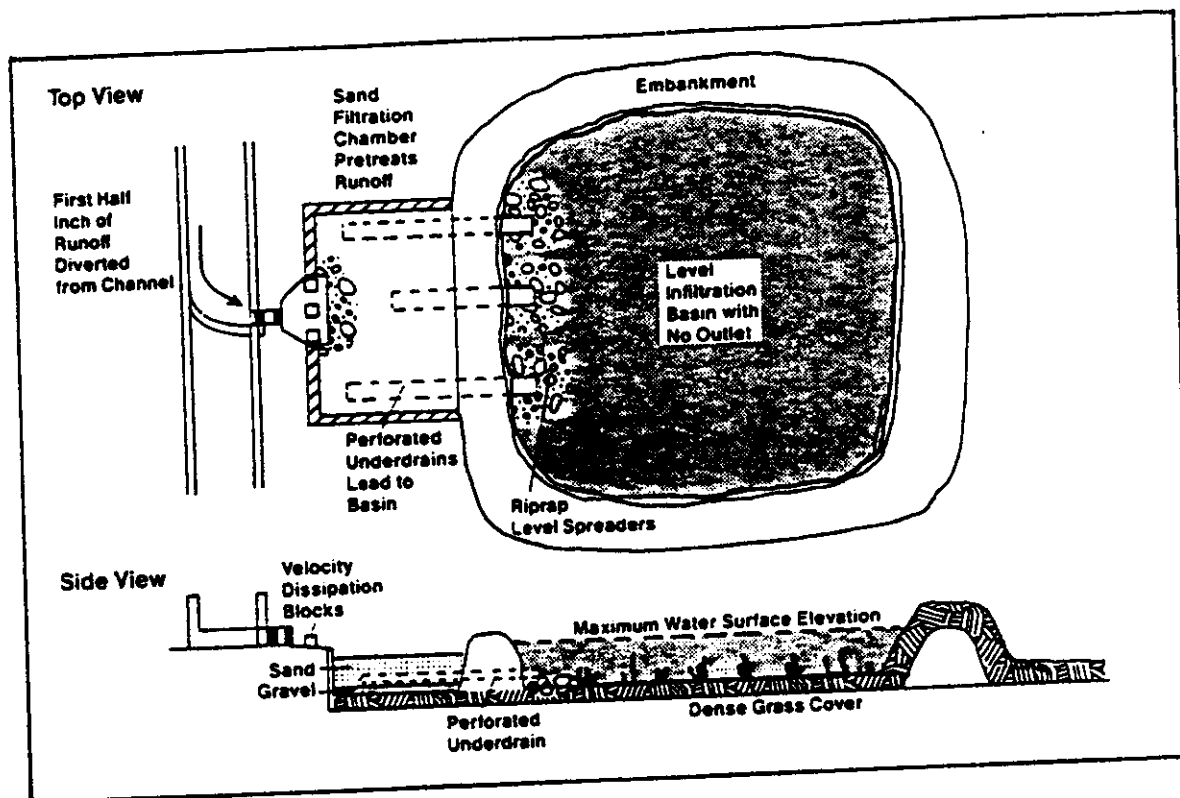


Figure 8. Schematic of Off-Line Infiltration Basin Design  
(Source: Schueler 1987)

### Infiltration Trenches

Infiltration trenches are an effective best management practice that can remove both particulate and soluble pollutants. Infiltration trenches are placed strategically so that storm water runoff will flow across and be trapped. The water is then allowed to infiltrate into the ground. The trenches are excavated and refilled with 1.5 to 2.5 inch stone (see Figure 9). A vegetative filter strip (see "Vegetative Systems - Filter Strips") must also be constructed just upstream of the trench to capture heavier sediments, trash, and other debris.

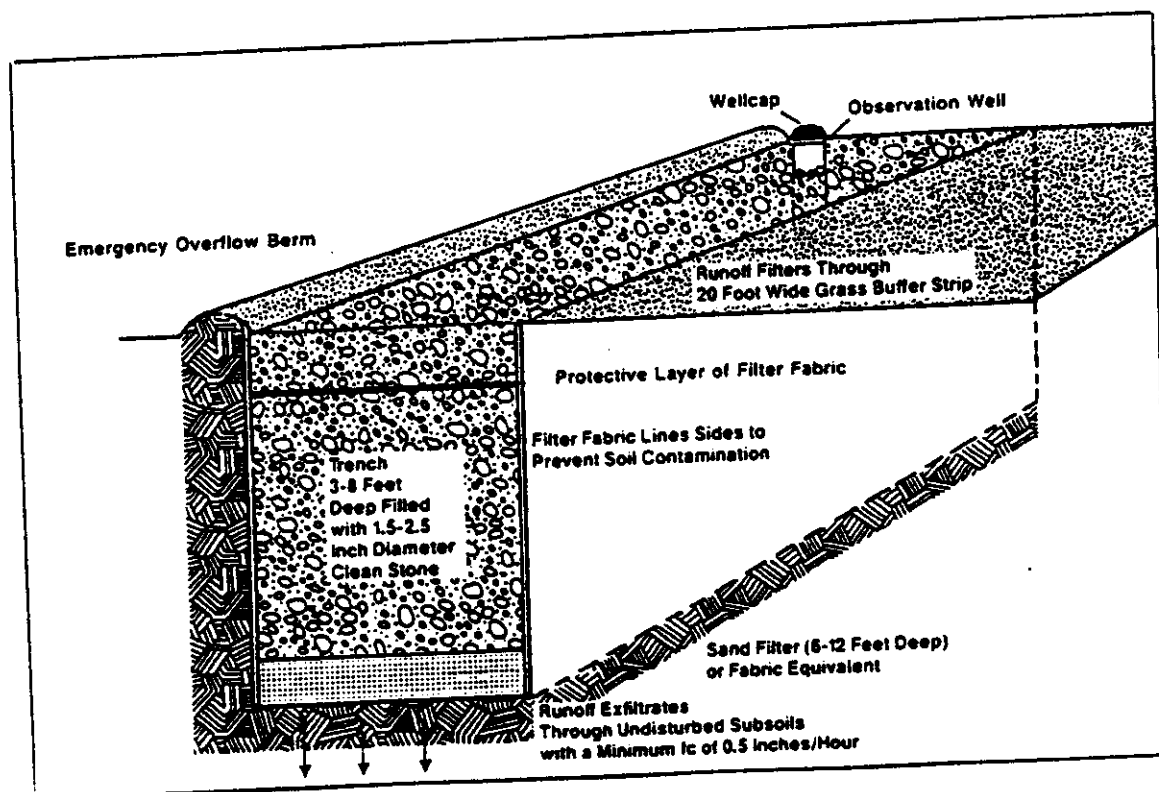


Figure 7. Schematic of Infiltration Trench  
(Source: Schueler 1987)

For infiltration trenches to be effective, base soils should have moderate to high permeability. Another site requirement is that the bedrock and groundwater tables should be a minimum of 2 to 4 feet from the bottom of the trench. Also, infiltration trenches are not recommended as the sole best management practice for development sites greater than 5 to 10 acres (Schueler 1987).

Pollutant removal mechanisms that are employed by infiltration trenches are through sorption, trapping, precipitation, straining, and bacterial degradation or transformation. The most efficient removal of pollutants occurs when it takes at least 6 hours, but no more than 72 hours for the storm water runoff to drain (or exfiltrate) from the infiltration trench (Schueler 1987).

Good design practice suggest that a monitoring well, a 4 to 6 inch diameter PVC pipe with a removable cap, be installed in the trench (Schueler 1987). The monitoring well allows an inspector to determine if the infiltration trench is working properly. A maintenance program that includes routine inspections, should also be included as part of the design of an infiltration trench. A routine maintenance and inspection schedule is necessary to prevent premature clogging of the trench.

There are two basic designs applications for infiltration trenches, surface and subsurface trenches. Some variations to the basic design are listed below.

#### Surface Trenches

- Median Strip Design (Fig. 10)
- Parking Lot Perimeter Design (Fig. 11)
- Swale Design (Fig. 12)

#### Subsurface Trenches

- Oversized Pipe Trench Design (Fig. 13)
- Underground Trench with Oil/Grit Inlet Design (Fig. 14)
- Under-the-Swale Design (Fig. 15)
- Dry Well Design (Fig. 16)
- Off-Line Trench System Design (Fig. 17)

NURP data did not report efficiencies for infiltration trenches but indicated that recharge management practices were capable of providing very effective pollutant removal (EPA 1983). Schueler estimates the long term removal rate to be 99% for sediment, 65 to 75% for total phosphorous, 60 to 70% for total nitrogen, 95 to 99% trace metals, 90% for BOD, and 98% for bacteria (Schueler 1987). The reader should be aware that Schueler (1987) based these removal rates on local modeling studies (NVPDC 1979) and field studies of the first flush phenomena by Griffin, et al. (1980).

The advantage of using infiltration trenches as best management practices are that they can be placed easily on strips of unutilized spaces of development, reduce volume of runoff directly leaving the development site, and can act to recharge site groundwater. The disadvantages of using infiltration trenches is that with out preventative maintenance, and proper education of maintenance personal, the trench can become quickly clogged and ineffective. The risk of groundwater contamination can be a possibility but no more so than other infiltration practices (Schueler 1987).

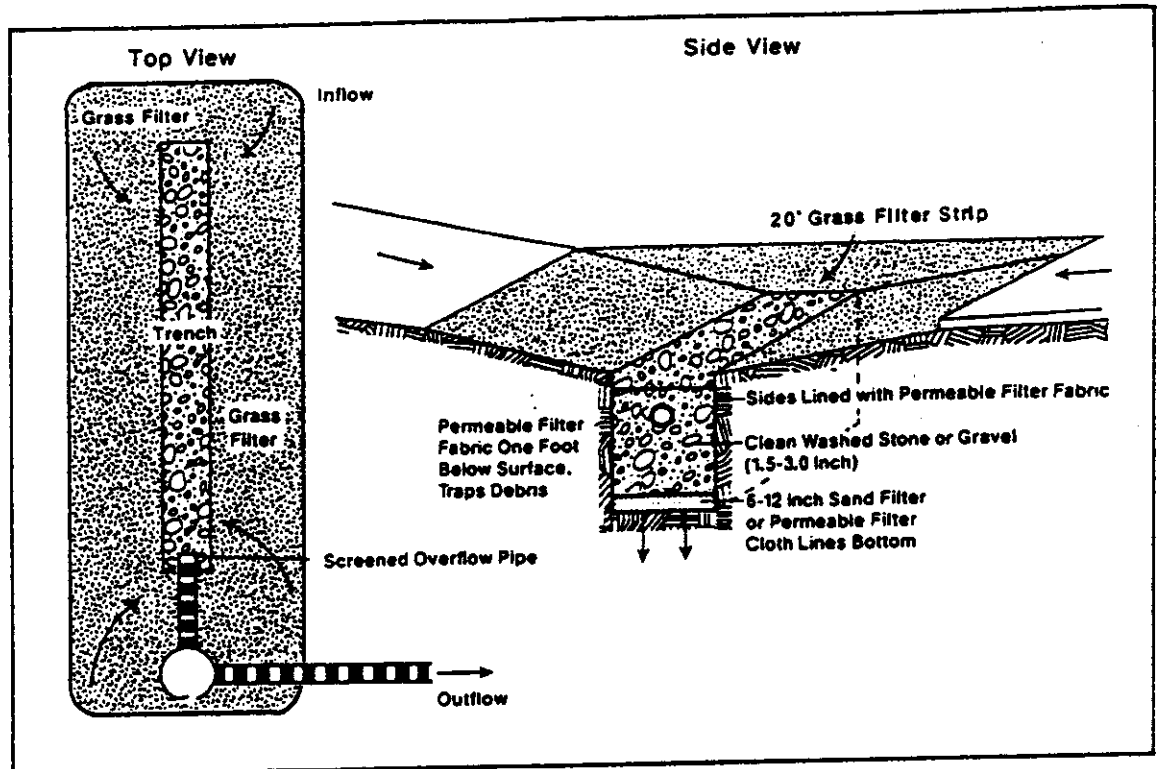


Figure 10. Schematic of Median Strip Trench Design  
(Source: Schueler 1987)

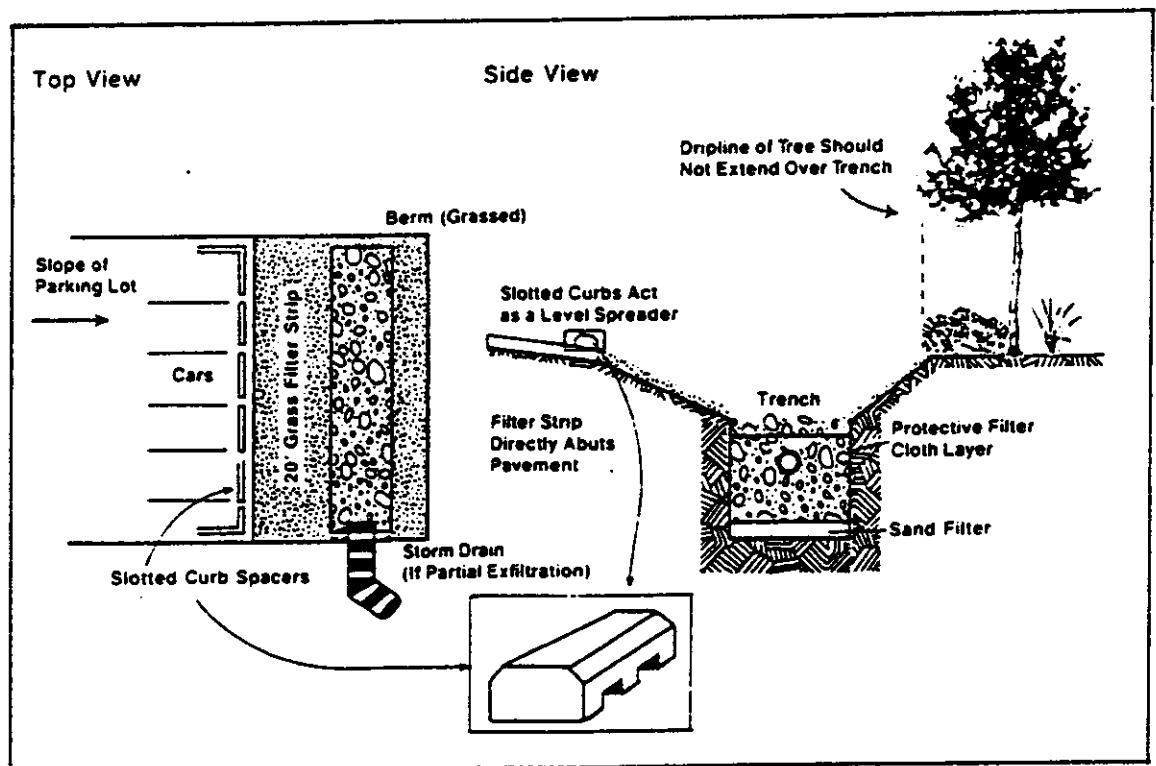


Figure 11. Schematic of Parking Lot Perimeter Trench Design  
(Source: Schueler 1987)

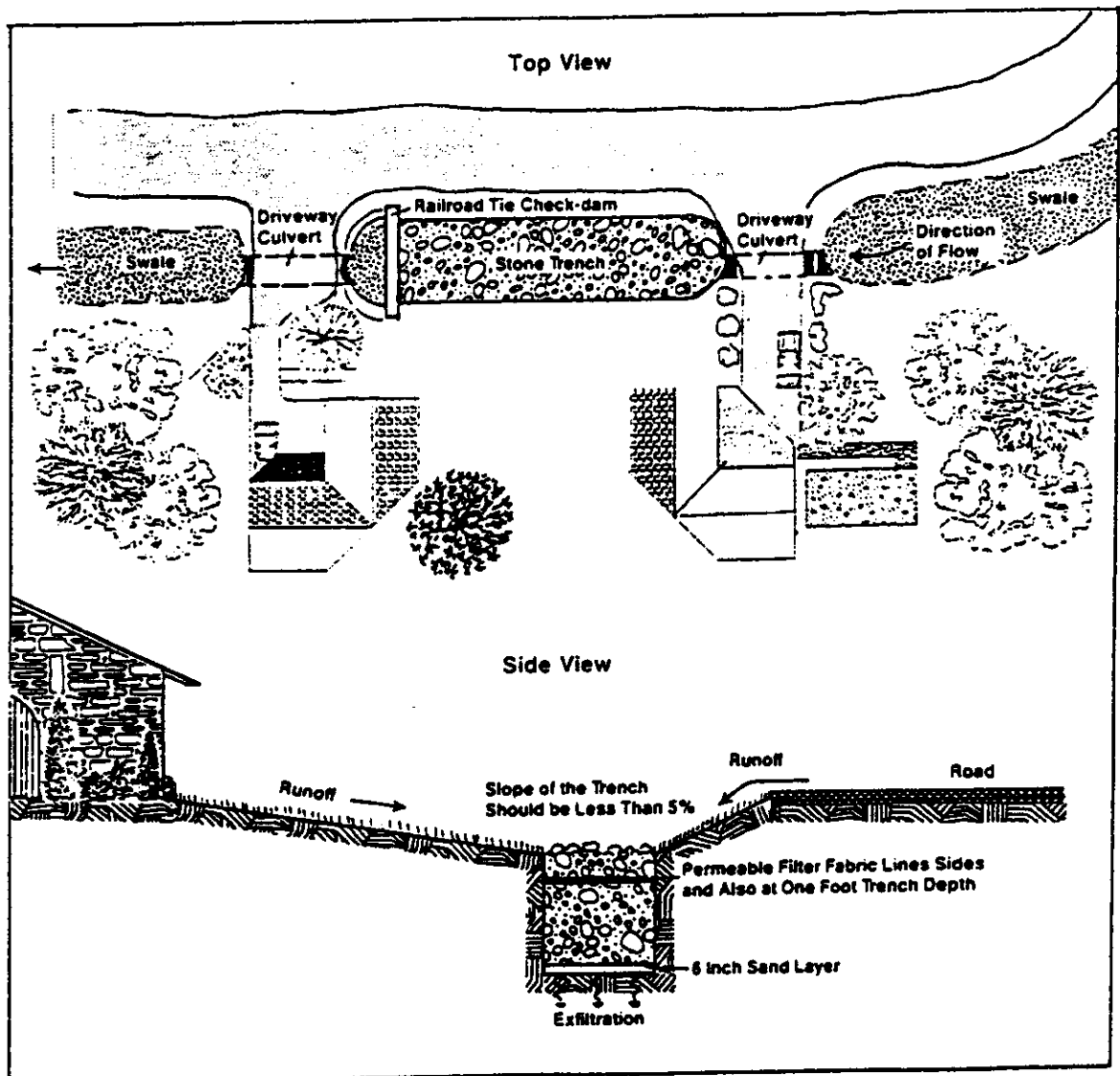


Figure 12. Schematic of Swale/Trench Design  
(Source: Schueler 1987)

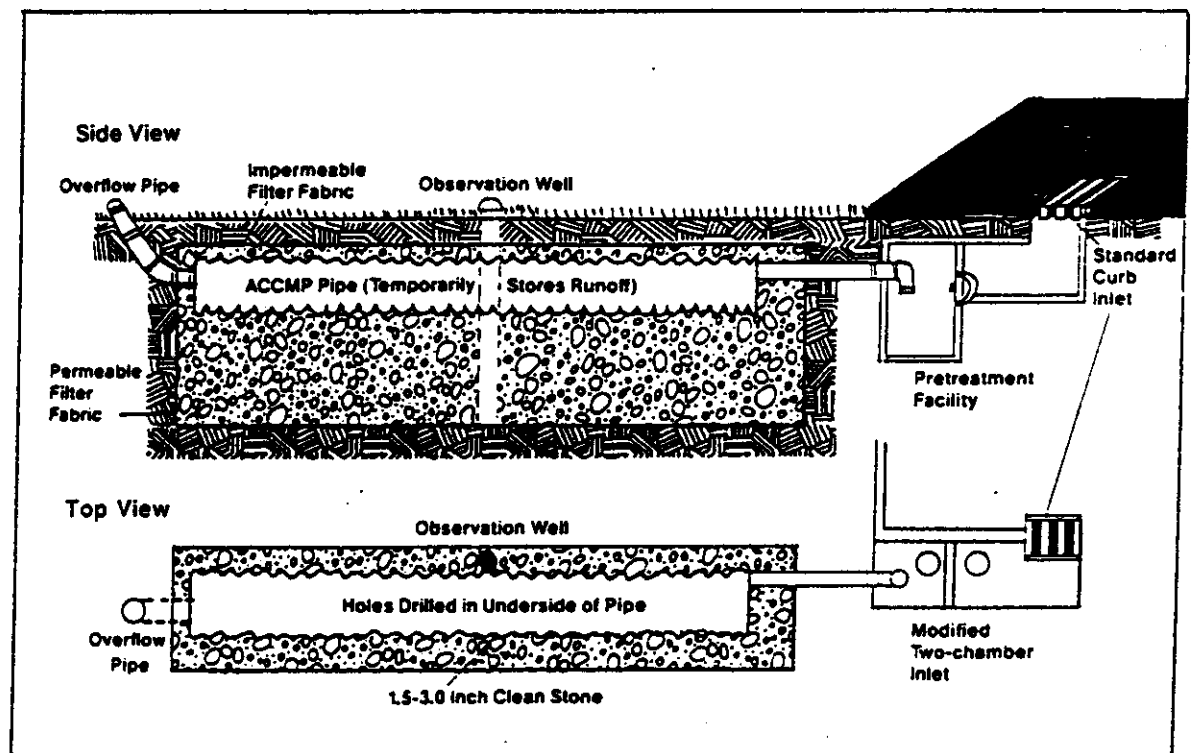


Figure 13. Schematic of Oversized Pipe Trench Design  
(Source: Schueler 1987)

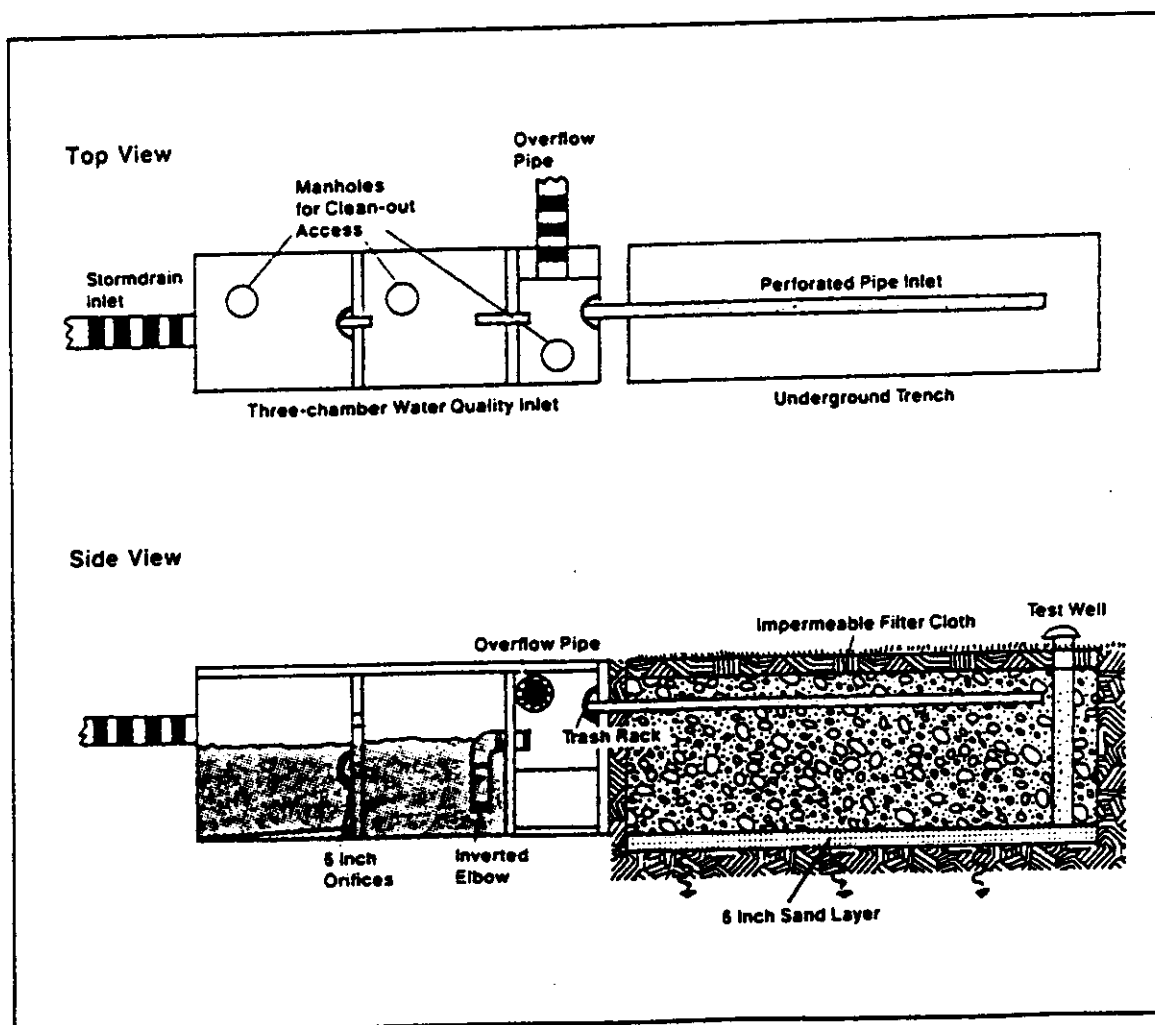


Figure 14. Schematic of Underground Trench with Oil/Grit Chamber  
(Source: Schueler 1987)

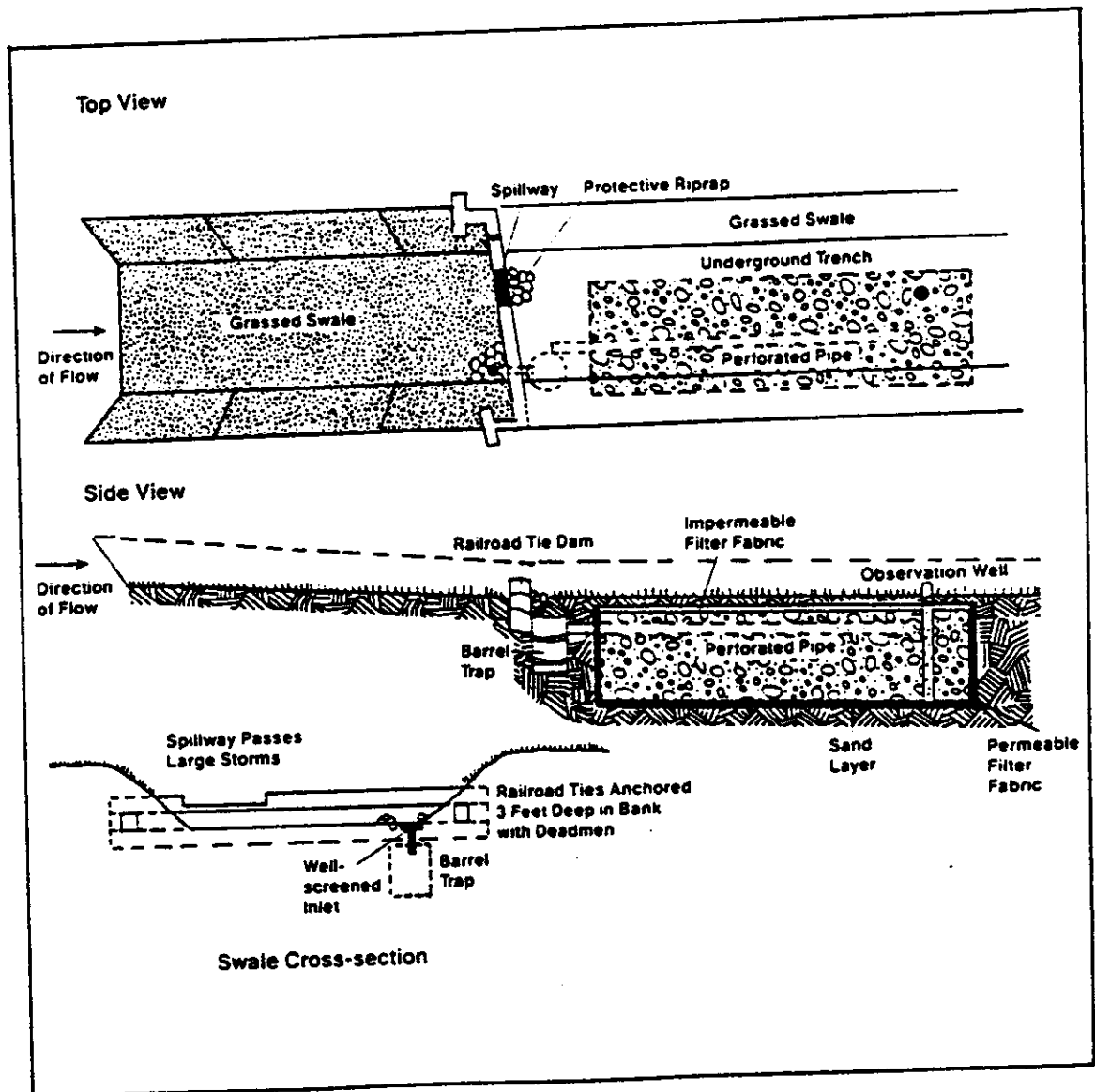


Figure 15. Schematic of Under-the-Swale Trench Design  
(Source: Schueler 1987)

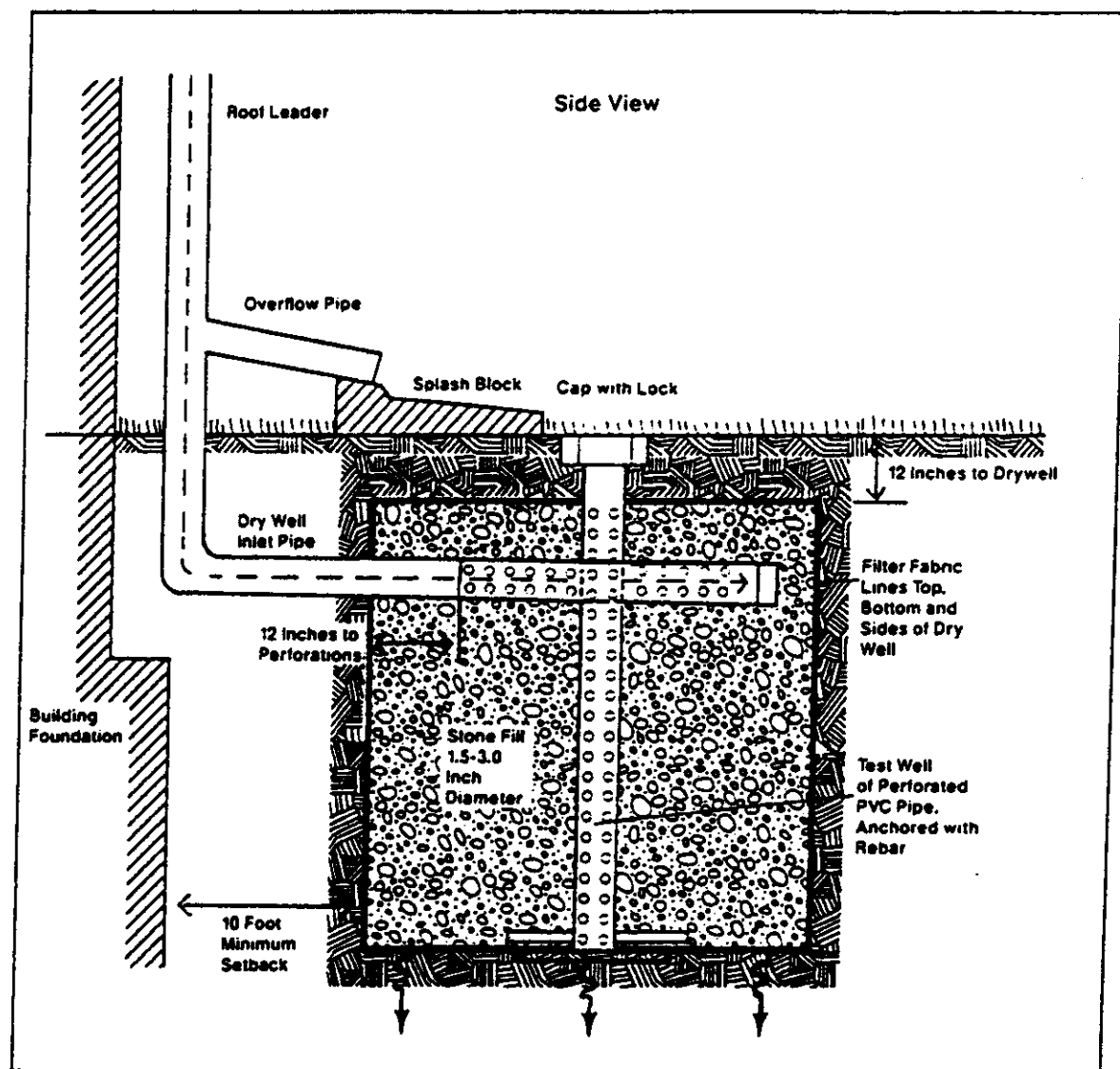


Figure 16. Schematic of Dry Well Design  
(Source: Schueler 1987)

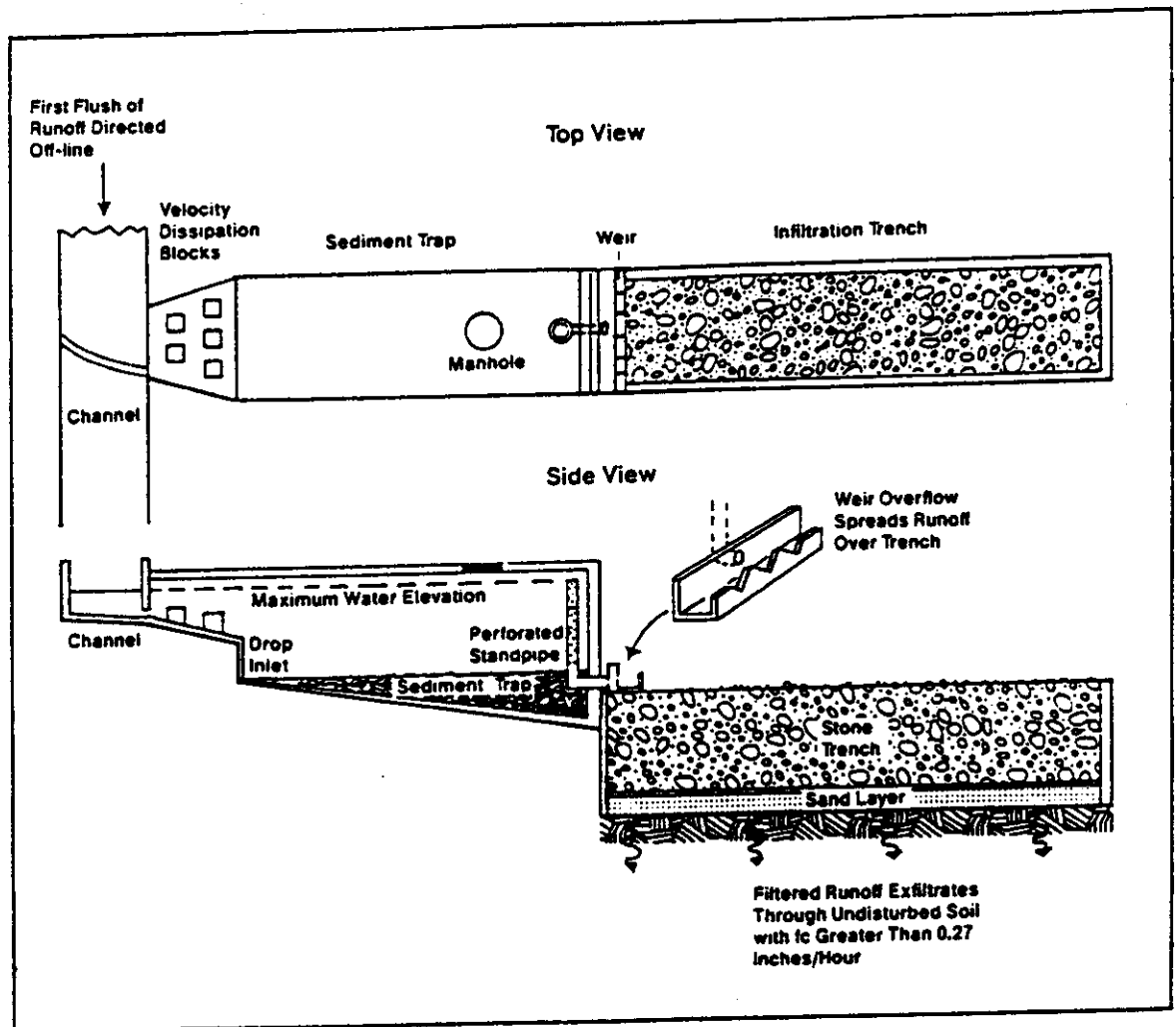


Figure 17. Schematic of Off-line Trench System Design  
(Source: Schueler 1987)

### Porous Pavement

Porous Pavement has the ability to allow storm water runoff to infiltrate rapidly through its pores. Porous pavement can typically be used in parking areas, however, it is not recommended for highway or street paving. Porous pavements have a similar cross-section as regular pavements. The top layer is porous pavement asphalt, then a filter layer, a stone (aggregate) reservoir, another filter layer, and a

filter fabric that covers the natural soil (see Figure 18). In porous pavement applications, the aggregate layer is much deeper to allow for the storage of storm water runoff until it can infiltrate into the ground (Schueler 1987).

Porous pavements are good best management practices for low volume traffic parking lots, with surface area between 0.25 and 10.0 acres. The use of porous pavement has very strict site limitations for the practice to be effective (see Figure 19). The soils must have moderate to high permeability. The slope of the site topography must be very mild (less than 5%). The water table and bedrock should be 4 to 6 feet below the porous pavement cross-section. Porous pavements can remove both soluble and particulate pollutants. Schueler (1987) indicates that porous pavements are unique in that they can almost completely reproduce the pre-development hydrologic regimen at a site, within a reasonable degree.

Porous pavements are not effective at removing coarse particulate pollutants, in fact, if they are allowed to reach the paved surface, failure could occur due to clogging of asphalt or filter pores. The use of porous pavement is primarily designed to remove pollutants falling onto the surface of the pavement from the atmosphere. The removal mechanisms that porous pavements use are sorption, trapping, precipitation, straining, and bacterial degradation or transformation (Schueler 1987). Similar to the other infiltration practices, a minimum of 6 hours and no greater

than 72 hours of exfiltration time is desired for proper pollutant removal.

NURP did not report efficiencies for porous pavements but indicated that recharge management practices were capable of providing very effective pollutant removal (USEPA 1983). Schueler (1987) provides data for two test sites, but the efficiencies were not compatible. It was speculated that differences in efficiencies existed because of varying design requirements.

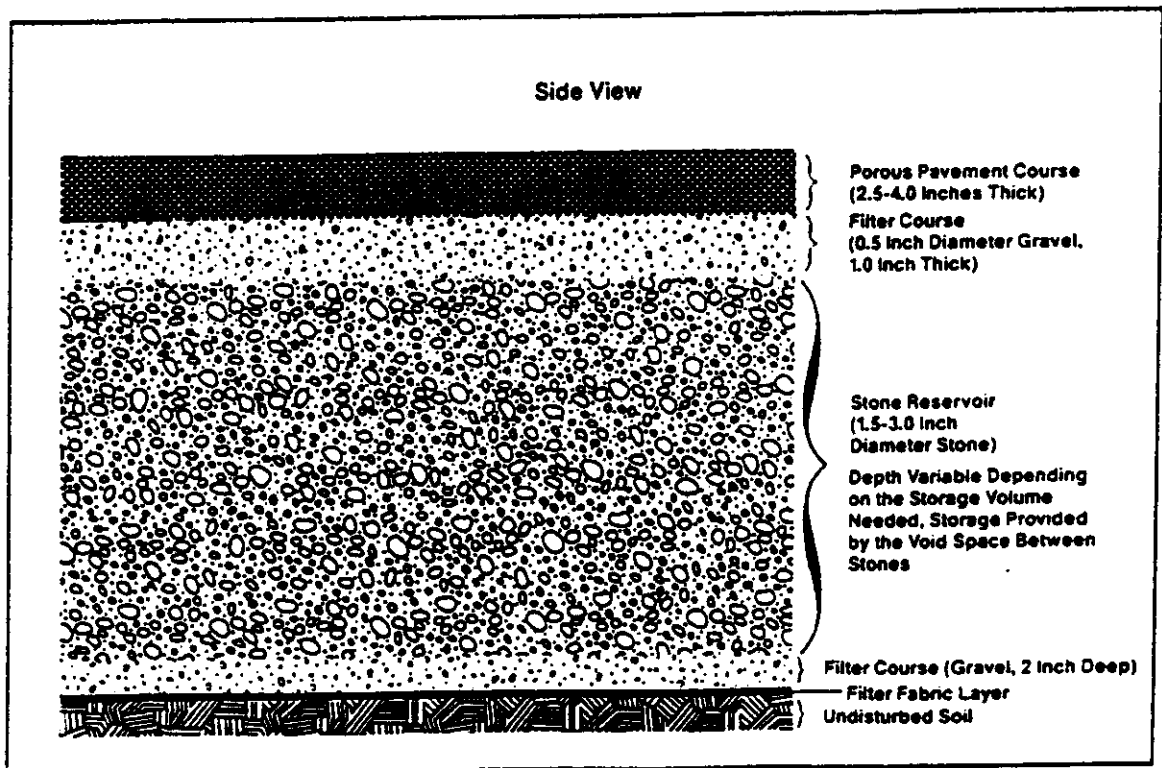


Figure 18. Schematic of Typical Porous Pavement Section  
(Source: Schueler 1987)

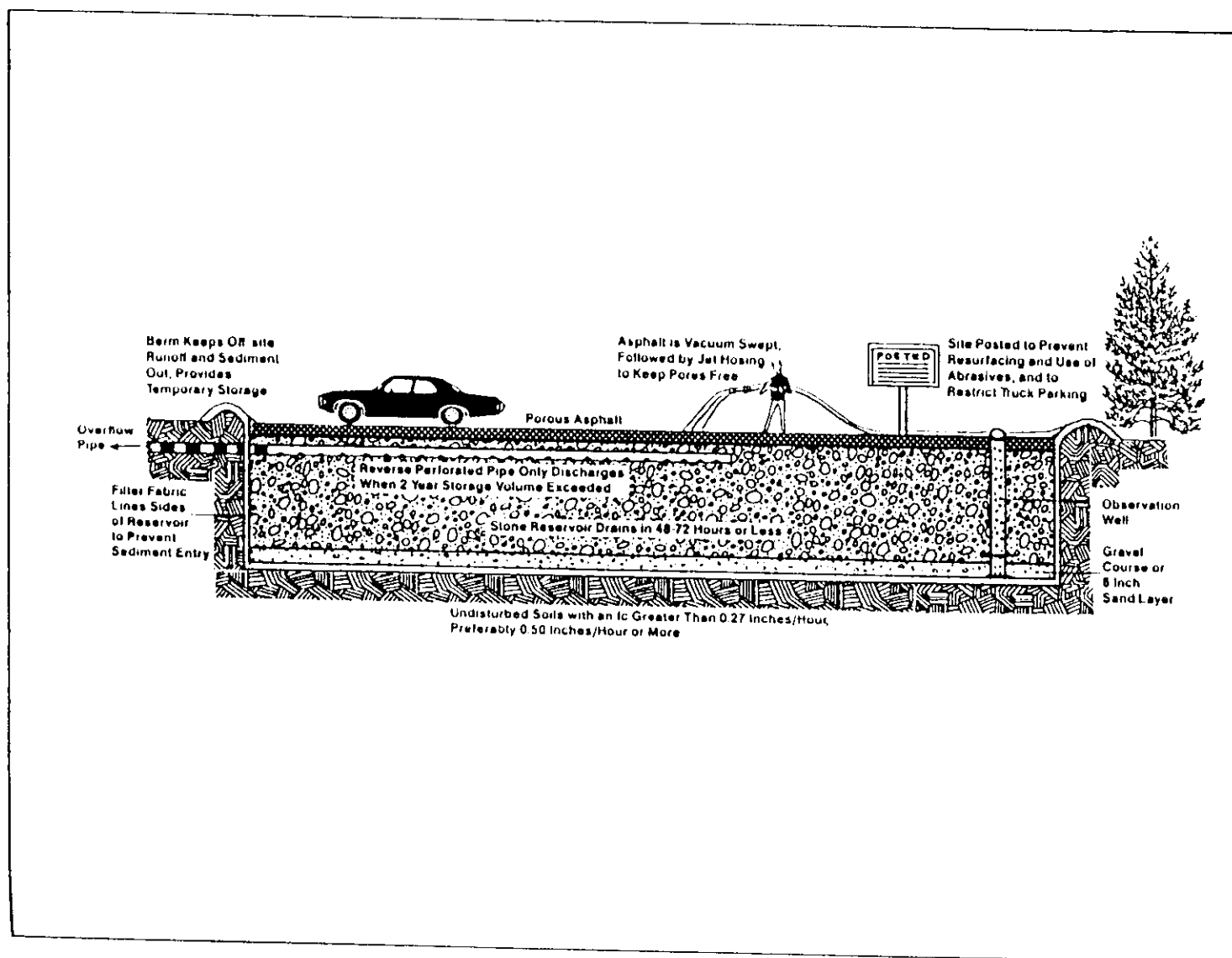


Figure 17. Design Schematic for Porous Pavement  
(Source: Schueler 1987)

A detailed construction specification and maintenance guideline for porous pavement construction is provided by Schueler (1987), in Chapter 7.

The advantages of using porous pavement as a best management practice are that it reduces land consumption, amount of storm water conveyance systems required, and provides a safer driving surface that reduces the risk of hydroplaning (Schueler 1987). Land consumption is reduced because porous pavements have the dual purpose of acting as a parking area and a best management practice. This in turn reduces the amount of land needed for other best management practices. The conveyance systems are reduced because curb and gutter systems are not needed. A curb and gutter system acts to concentrate flows which is not desirable for porous pavements. The driving surface of porous pavements is rougher than normal parking lot pavements, thereby lowering the risk of hydroplaning.

The major disadvantage is that if porous pavement does become clogged, the cost of rehabilitating the pavement system is very costly. The careful design and construction of porous pavement is very important. A high degree of workmanship for installing porous pavement is necessary and is unlikely available through low bid construction site work. High intensity storms may not be infiltrated by the porous pavements quickly enough and temporary flooding could occur. Another possible disadvantage is that groundwater could be

contaminated, but no more so than other infiltration practices.

### Water Quality Inlets (Oil and Grease Removal)

Water quality inlets are permanent storm water management control structures that remove sediment and hydrocarbons from urban storm water runoff (see Figure 20). Water quality inlets are typically the best management practice of preference when high volumes of vehicular traffic or high petroleum inputs are expected.

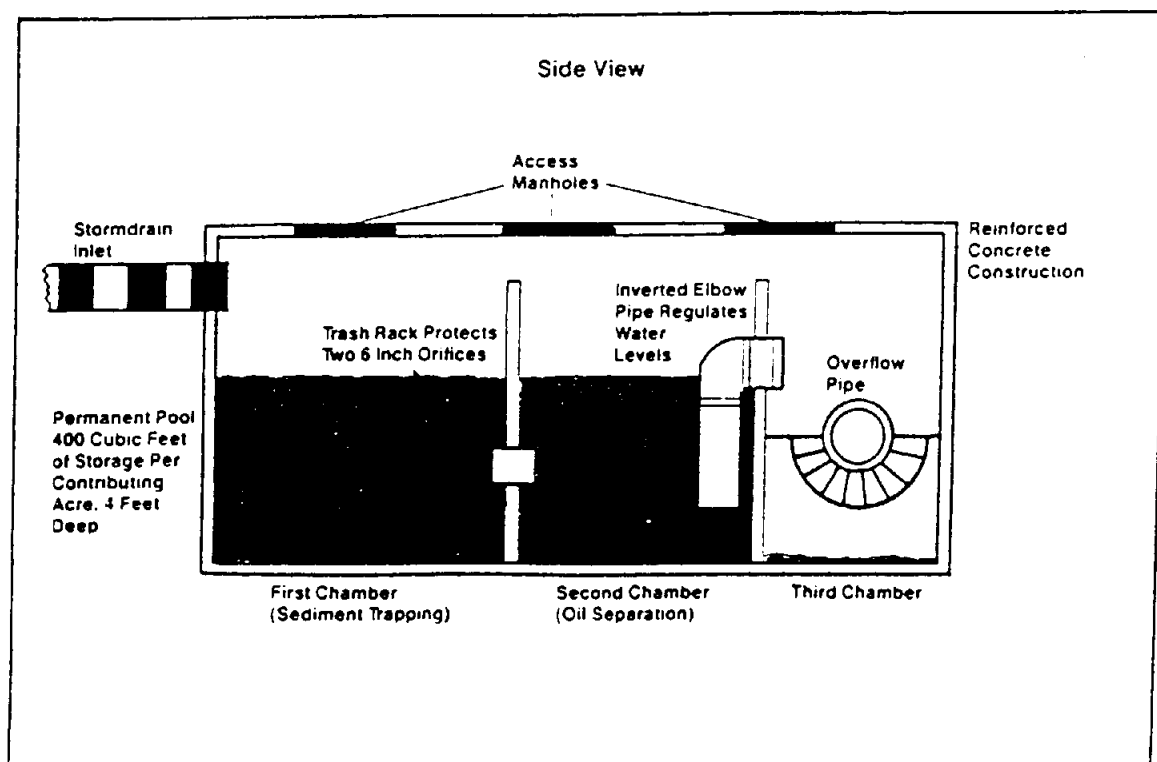


Figure 20. Schematic of Three Chamber Water Quality Inlet  
(Source: Schueler 1987)

Schueler (1987) expects that only moderate pollutant removal can occur because of the relatively short time the storm water runoff can be detained. Moderate removal efficiencies of coarse sediments, petroleum products, and debris is expected, but soluble or fine particulate pollutants are expected to pass through with minimal removal. Thus the water quality inlet is primarily a pretreatment to be used in conjunction with other best management practices.

Basic design practices dictate that a water quality control inlet should not differ from an ordinary storm water runoff control inlet (i.e. similar drainage area considering both percent impervious and slope of the drainage area). A cut off value of 1 acre is the typical maximum drainage area that can be treated by a water quality control inlet.

NURP did not address water quality inlets (USEPA 1983). Schueler (1987) states that the pollutant removal rates have never been tested in the field. Oil and grease are expected to be efficiently removed but generalizations regarding other pollutants cannot be made at this time.

Advantages of using water quality inlets as best management practices are that they reduce coarse sediment, debris, and hydrocarbon loadings that can clog, or fail, infiltration practices. Water quality control inlets can easily be incorporated into curb and gutter storm water management systems. These inlets are unique in that they can unobtrusively pre-treat storm water runoff before it enters

other best management practices. Disadvantages include limited capability for pollutant removal, and the frequent clean out and disposal of accumulated pollutants is required.

### Vegetative Systems

Vegetative Systems are vegetative areas, natural or engineered, that are established to enhance pollutant removal and habitat value (Schueler 1987). Natural vegetative areas are environmentally acceptable and aesthetically pleasing. Engineered vegetative areas are slightly less environmentally acceptable and aesthetically pleasing. Natural vegetative areas are difficult to incorporate into development designs because a natural vegetative area does not always exist where site demands dictate. This is why natural vegetative areas are prone to high failure rates. Engineered vegetative areas are easier to incorporate into development designs because of the flexibility associated with the placement of the vegetative area. Engineered vegetative systems provide more efficient removal of pollutants than natural systems. All vegetative systems typically have high failure rates because of the lack of proper maintenance and inspection. Examples of vegetative systems are grassed swales, filter strips, urban forest, basin landscaping (modification), and constructed wetlands (see Figure 21). Vegetative systems are not generally capable of entirely controlling increased storm water runoff (i.e. detention ponds and retention ponds) and/or the export of pollutants from a particular site but that they

can improve the performance of other best management practices (Schueler 1987). Schueler and others, have indicated that vegetative systems should be an integral part of every development site.

The NURP did not completely assess vegetative systems but indicated that additional study could substantially enhance performance capabilities (USEPA 1983). Three vegetative systems were studied, all grassed swales. Two swales failed to show any water quality enhancement. For the third swale, pollutant removal was about 50% for metals, and around 25% for COD, nitrate, and ammonia. Organic nitrogen, phosphorous, and bacteria were essentially unaffected (USEPA 1983).

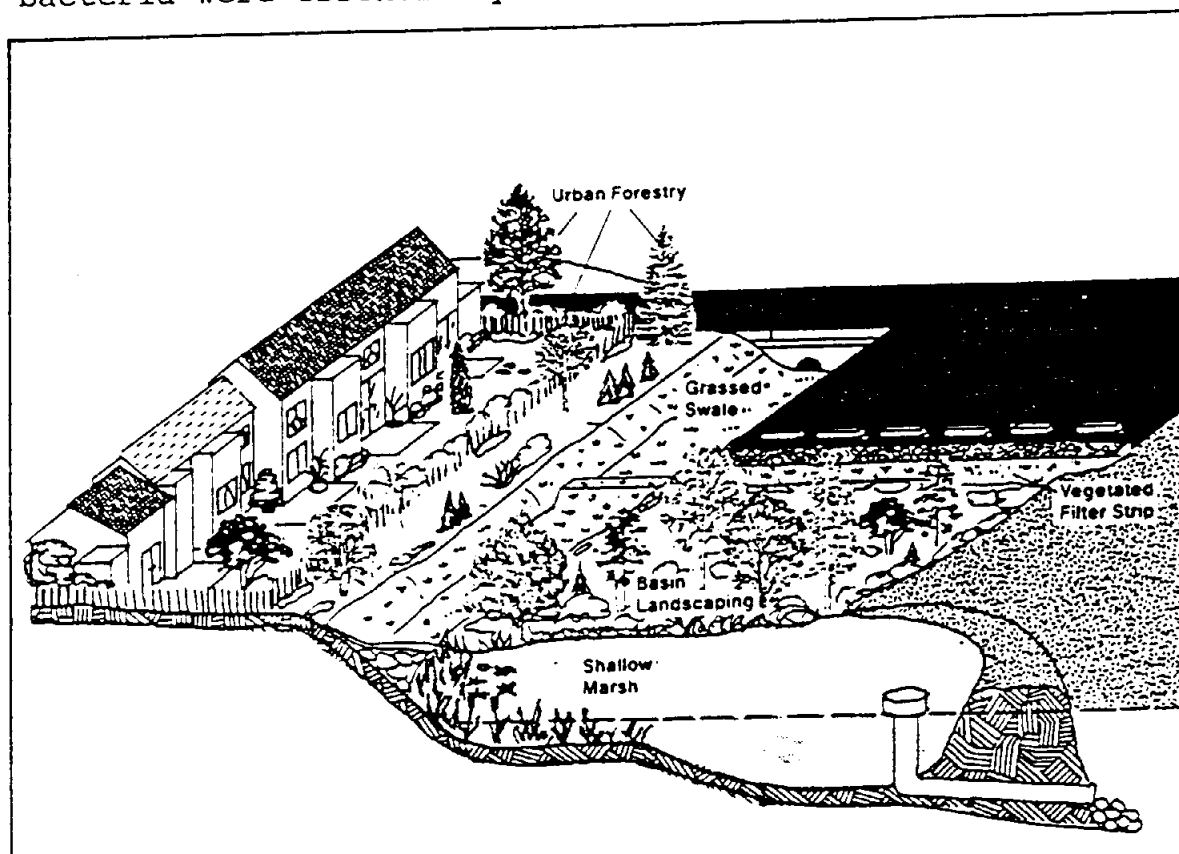


Figure 21. Schematic of Vegetative Systems  
(Source: Schueler 1987)

### Grassed Swales

Grassed swales are an excellent best management practices for developments zoned as single family residence (low density). Grassed swales are also used for the medians of highways. The use of grassed swales reduces impervious area (areas that would have been needed for curb and gutter systems), aids in slowing, or controlling, storm water discharges - which in effect lengthens the time of concentration. Time of concentration is defined as the time it takes a drop of rain to travel from the most remote point of the drainage basin to a downstream point of interest (i.e. an outlet).

Grassed swales benefit water quality by reducing storm water runoff velocities and potential scour, and the filtering of pollutants by the grass. Removal by infiltration, and sorption, is limited. OWML (1983) indicates that nutrient and trace metal export was slightly increased. Other studies (Kercher et al. 1983 and Yousef et al. 1985) indicated moderate to high removal of particulate pollutants. Schueler (1987) indicates that at least moderate removal of particulate pollutants can "more than likely" be expected during small storms.

There seems to be only limited consensus on the best roles and optimal design standards for swales. The combined effects of reducing impervious area, controlling storm water runoff, and improving water quality can all be incorporated in

swale designs (see Figure 22). Some swales are designed only for controlling storm water. Others may be designed for improving water quality, while others may be designed to reduce impervious area. This high degree of variability in design masks the trapping efficiencies swales may actually have.

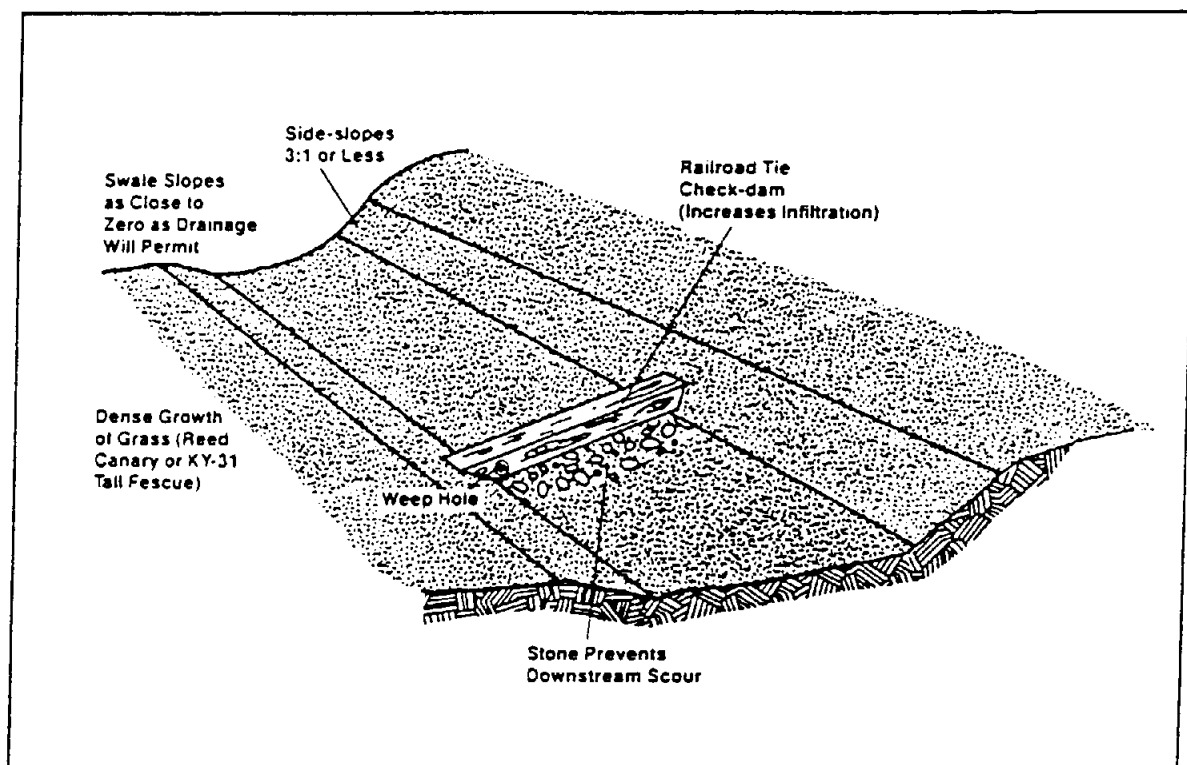


Figure 22. Schematic of Grassed Swale  
(Source: Schueler 1987)

Grassed swales are typically not recommended as best management practices if gradients of the swales exceed 5.0%, if the maximum velocity exceeds 3.0 feet per second, or if the peak runoff discharge rate exceeds 5.0 cubic feet per second. In most cases, it is recommended that other best management practices be used in combination with grassed swales (Schueler 1987).

A big advantage of using grass swales as a best management practices is that most maintenance on the swale is performed by the adjacent land owner. The maintenance would mainly consist of typical lawn care functions such as mowing, watering, and fertilizing so that a good stand of grass is maintained. However, landowners should be made aware that the grassed swale is not a "ditch". A disadvantage of using grass swales is that flow capacity is limited and storm water runoff from large design storms can cause brief, minor flooding. Grassed swales typically do not allow infiltration (Schueler 1987). Due partly to the fact that contact time in the swale is typically only 5 to 20 minutes and partly due to the fact that swales are heavily compacted, making for very slow infiltrating of water through the soil profile.

### Filter Strips

Filter strips are useful for improving water quality, environmental habitat, and aesthetics of a development site. At this time the removal of pollutants by filter strips are not completely understood. Hayes and Dillaha have made

recommendations on trapping efficiencies for sediment using vegetative filter strips (Hayes and Dillaha 1992 and Dillaha and Hayes 1992). Dillaha (1986) has also studied long term effectiveness and required maintenance. He suggests that berms be placed at 50 to 100 feet intervals perpendicular to the top edge of the vegetative filter strips (see Figure 23).

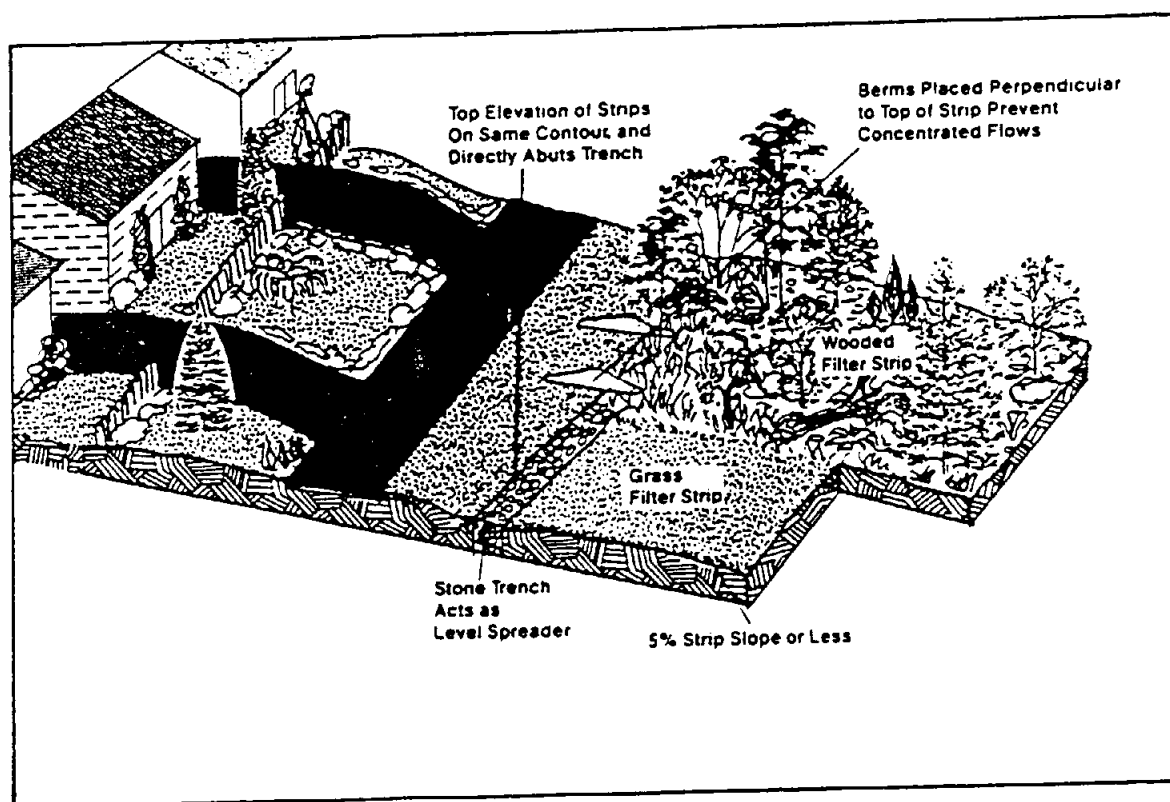


Figure 23. Schematic of Vegetative Filter Strip  
(Source: Schueler 1987)

Barfield (1977) indicates that vegetative filter strips are effective in removing particulate pollutants such as sediments, organic materials and many trace metals. These test were conducted on small test plots and related to predicting the sediment transport in grass media. Schueler (1987) indicates that the rate of removal of pollutants is a function of the width, slope, soil type (permeability), size of the contributing drainage area, and the discharge velocity. Phillips (1988) has developed two equations to model the above parameters, using an "ideal filter strip" to determine widths required for buffer zones adjoining estuaries. One equation is based on hydraulics and the other equation is based on detention.

Vegetated filter strips can only be used for best management practices that allow the discharge to enter in a sheet flow manner. This is difficult to engineer, and thus represents a significant disadvantage. Vegetative filter strips are also not recommend to be the primary best management practice for areas greater than 5 acres (Schueler 1987). Vegetative filter strips must be periodically checked for short circuiting through or around the strip. Short circuiting of the vegetative filter strip virtually reduces any water quality enhancement.

Additional investigations of vegetative filter strips are proposed by McCutcheon, Hayes, and Klaine (1993). These investigators will evaluate the efficiency of vegetative

filter strips to improve water quality.

### Urban Forest

The best management practice, urban forestry, is primarily the landscaping of a development site. If landscape architects and engineers combine their skills to design and plan projects, a residential development consisting of trees and shrubs, and other ground cover can occupy 50% of the site (Schueler 1987). Increased vegetation decreases impervious and/or semi-impervious areas. With decreased impervious area, smaller runoff volumes are generated, and peak flow rates are lowered.

The water quality benefit from urban forest arises from pollutant removal taken up by the root systems, as well as reducing soil erosion. The overall amount of pollutant trapping varies and is poorly understood. Some air pollution can be reduced by urban forest. This could then reduce the pollutants falling from the atmosphere, which could indirectly improve water quality.

Urban forest require that proper planning be involved in the landscaping of residential lots or the residential community. It is not practical to use urban forest management practices for areas of a lot or residential community that contain play grounds or walking paths. These areas experience heavy foot traffic, which could cause erosion.

Urban forest are valuable in providing habitat environments for a variety of wildlife. Trees and shrubs

provide a natural temperature buffer for thermal sensitive aquatic life. Trees and shrubs also help to control erosion. Disadvantages of urban forest could be recent concerns regarding the release of hydrocarbons from stands of pine trees in large Southern cities (i.e. Atlanta, Georgia). Schueler (1987) indicates that higher nutrient loadings could occur due to pollination, and/or autumn leaf falls

#### Basin Landscaping

The most important best management practice is basin landscaping (Schueler 1987). It is important for the designer to be familiar with the watershed that the development will impact and make use of the existing natural landscape (see Figure 24). Basin landscaping uses topography and vegetation to stabilize erosion due to storm water runoff and to improve water quality by reducing sediment loads and increasing the uptake of pollutants by the vegetation.

Basin landscaping is important in the design of all other best management practices. For example, the maintenance and operation of retention ponds can be greatly enhanced if proper basin landscaping exists. Aquatic plants can be grown near the shore line of the pond such that soluble pollutant removal is enhanced. A vegetative filter strip used as the inlet into the pond can be used to reduce entering storm water runoff velocities and initiate removal of the larger particulate pollutants.

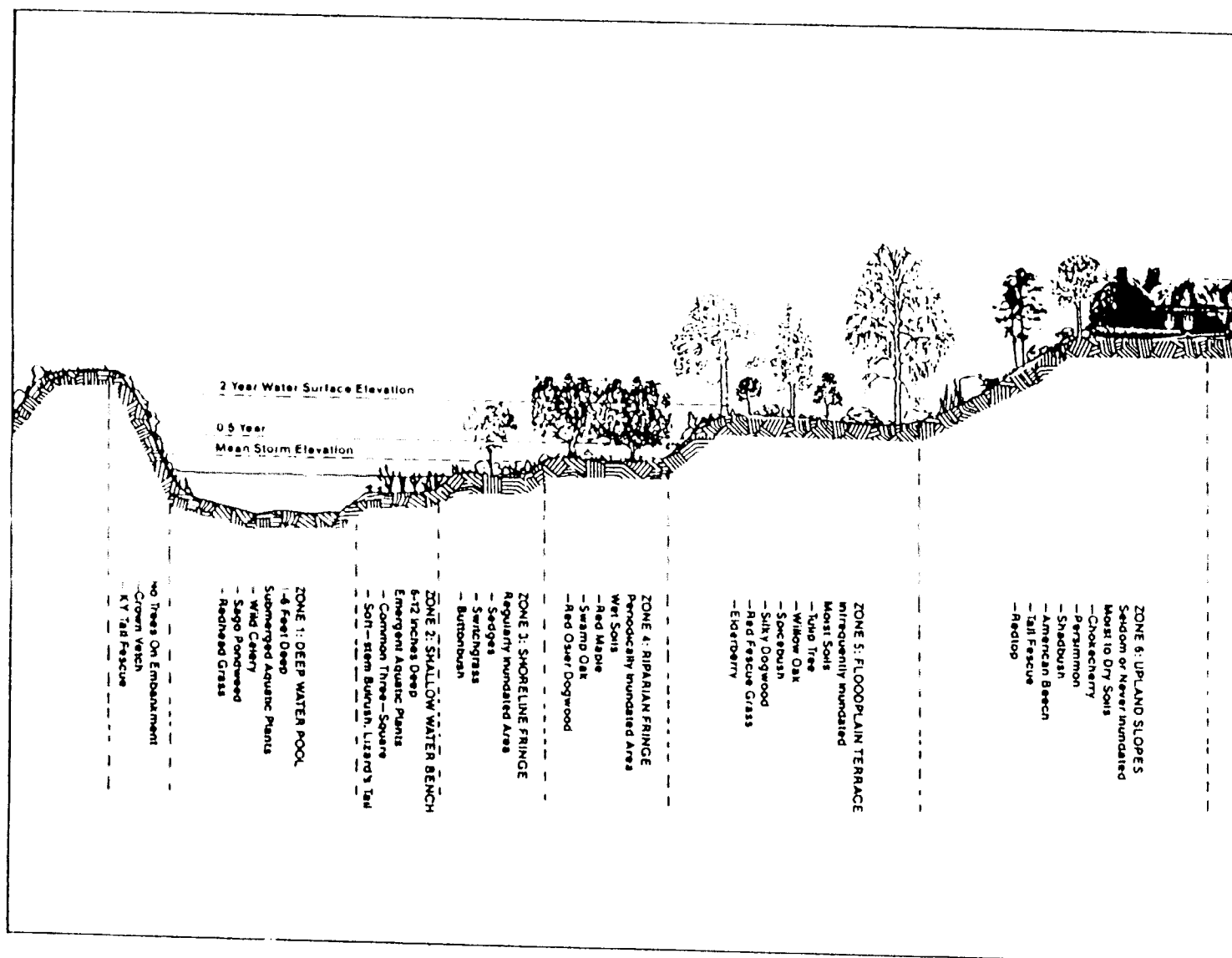


Figure 24. Basin Landscaping Zones for Watershed  
 (Source: Schueler 1987)

### Constructed Wetland

The design of a shallow marsh (or constructed wetland) is very similar to basin landscaping. Again, topography and vegetation are essential in designing a constructed wetland. The best management practice of using a constructed wetland is defined as the creation of a marsh for the specific purpose of controlling storm water runoff and to improve the water quality leaving a development site. The use of constructed wetlands as a best management practice has numerous ecological and apparent water quality benefits but their trapping efficiency for specific pollutants has not been evaluated. The following guidelines should be considered for successfully establishing wetlands (Schueler 1987, Athanas 1986, Lakatos and McNemar 1986, and Maryland SCS 1986):

- Plant propagation is most reliable when live plants are transported from existing marshes or by using dormant rhizomes from nursery stock.
- Water depth must be maintained relatively constant so that the growth and colonization of the wetland will proceed naturally.
- Optimal nutrient removal occurs in shallower marshes.
- Surface area of the marsh, as a rule of thumb, should consist of 2% to 3% of the total surface area of the contributing drainage basin.
- Planting strategies should detail that at least two primary marsh plants (healthy and rapid colonizing to that drainage basin) should be planted alternately.
- At least three other secondary marsh plants should also be planted which will further increase the probability of successful establishment of a constructed wetland.

The primary disadvantages of constructed wetlands is that

little is known about wetland hydrology and pollutant removal. It is therefore quite difficult for designers to incorporate existing or constructed wetlands into storm water management plans. There are also policy concerns regarding existing wetland use. Since the assimilative capacity of wetlands are difficult to determine, it would be best if storm water management plans were designed to use other best management practices - at least until research has unlocked these mysteries. For now, though, wetlands can act as a backup if other engineered management practices fail. Further, wetlands represent the habitats for numerous species and act to ensure the ecological dynamics of these species.

Wetlands destruction and use also requires extensive permitting. This permitting process can be stopped or slowed by citizen concerns. To avoid costly delays, engineers and landscape architects should fit developments around existing wetlands, provide best management practices to protect wetlands, and add wetlands only to ensure full protection of existing wetlands from increased storm water runoff. The involvement of organized environmental groups, concerned neighbors, and regulatory agencies in the planning stages of the development can identify impacts and reduce concerns.

#### Nonstructural Best Management Practices and Other Approaches

A nonstructural best management practice is a regulation or guideline that is enforced to improve water

quality/quantity control. A typical nonstructural best management practice includes local storm water management, sediment, or erosion control ordinances (See also "Legal Aspects of Storm Water - Current Regulations" for SC's state wide plan). Other nonstructural best management practices involve education regarding the disposal of hazardous waste (household cleaning supplies, grease and oil, etc.). Other programs could involve the disposal, application, or handling of pesticides, herbicides, and fertilizers. Nonstructural best management practice could also include an ordinance for disposal of pet wastes.

Other best management practices that do not fit in the category of structural, nor in the nonstructural best management practices, include rock check dams, silt fences, hay bales, quick growing grasses, stone drive pads for entering and leaving construction sites, and many more can be used effectively to control storm water runoff and manage erosion. An excellent source for these types of practices can be found in the **Virginia Erosion and Sediment Control Handbook 1991**, or the most current edition (VA SCS 1991). This handbook provides design drawings, standards and specifications, and maintenance schedules. South Carolina's handbook (SCLRCC 1985) is somewhat out of date, but does contain some of the same information.

One other of these "non category" best management practices, street sweeping, has been studied to determine its

effectiveness at improving water quality. NURP conducted studies on street sweeping and found that no water quality enhancement was achieved and in some sites water quality was actually degraded by the street sweeping practice (USEPA 1983). American Public Works Association (APWA 1991) confirms this finding and indicated that some municipality sweep operators swept debris into the nearest catch basin. It should be noted that street sweeping is an aesthetically pleasing management practice but it can be detrimental to water quality. Street sweeping should be viewed as a service to maintain the quality of life, and not included in storm water management plans or policies, except to note that additional treatment may be needed to accommodate the sweeping.